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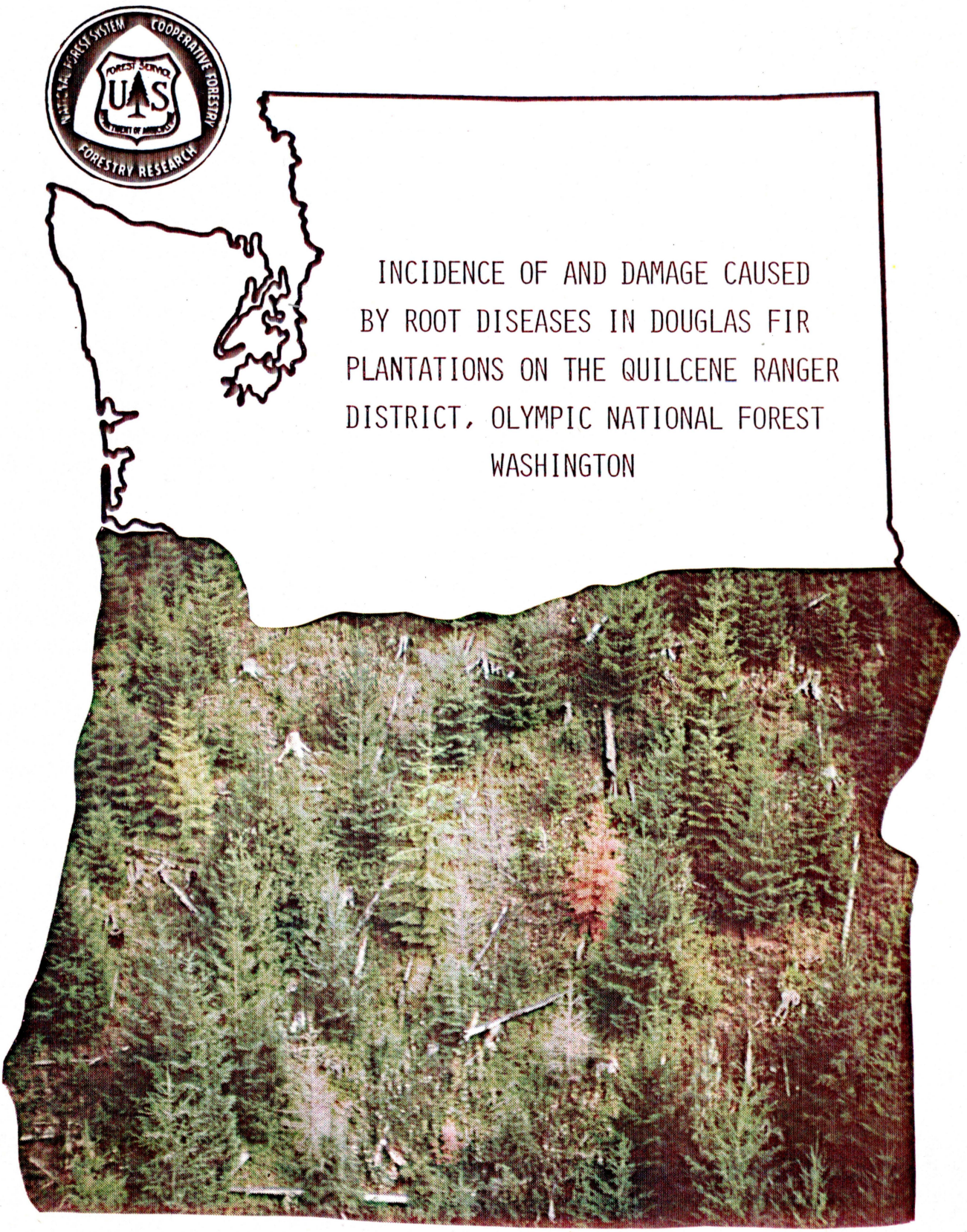

INCIDENCE OF AND DAMAGE CAUSED BY ROOT DISEASES IN DOUGLAS FIR PLANTATIONS ON THE QUILCENE RANGER DISTRICT, OLYMPIC NATIONAL FOREST WASHINGTON

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Incidence of and Damage Caused by Root Diseases in Douglas-Fir Plantations on the Quilcene Ranger District, Olympic National Forest, Washington

by

Gregory M. Filip and Donald J. Goheen
Plant Pathologists
Forest Insect and Disease Management
State and Private Forestry
Portland, Oregon

Others who rendered technical assistance include
J. Wortendyke, R. Harvey, C. Schmitt, B. Lane, K. Robbins,
and the Quilcene District personnel

Abstract

Forty-three 9- to 27-year-old Douglas-fir plantations were surveyed by air to measure incidence of tree mortality. Eleven randomly chosen plantations were examined on-the-ground to establish cause of mortality. Total calculated mortality averaged only 1.1 trees per acre, but was clustered within plantations, resulting in understocked openings 1/10 to 1/4 acre in size. Most mortality was caused by *Armillaria mellea* or *Phellinus weirii*. No statistically significant correlations occurred between total mortality and plantation age, elevation, planting density, method of tree establishment, or silvicultural treatment. A significant relationship was found between Douglas-fir mortality due to root diseases and number of adjacent infected old-growth stumps. Recommendations for minimizing future losses due to root diseases are discussed.

Introduction

On August 31, 1976, and May 17, 1977, plantations on the Quilcene Ranger District, Olympic National Forest, Washington, (Figure 1) were examined by the authors and District personnel. Several plantations showed extensive mortality due primarily to root diseases caused by *Armillaria mellea*, *Phellinus weirii*, and *Verticicladiella wagenerii*. Some affected plantations had been thinned and fertilized.

In August and September 1977, an extensive survey of randomly selected plantations was conducted on the District. Evaluation objectives were to determine (1) incidence of tree mortality, (2) cause of mortality, and (3) relationships, if any, between various plantation characteristics and incidence of mortality.

Methods

One-hundred forty plantations on the District were classified by age, stocking density, elevation, silvicultural treatment, and method of tree establishment. Only plantations with trees 10 years old or older were selected for further sampling, since preliminary observations indicated insignificant mortality in younger plantations.

Forty-three plantations were selected for examination using a random number table. Selections were weighted to yield proportionate numbers of plantations based on silvicultural treatments and method of tree establishment (Table 1, Figure 2).

Most plantations surveyed were established on sites previously occupied by mixtures of western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*). Plantations ranged in size from 4 to 140 acres and in age from 9 to 27 years. Seventy-nine percent of the plantations had been planted with Douglas-fir, 13 percent had been seeded with Douglas-fir, and 8 percent had been regenerated naturally. Ten percent of the plantations had been thinned to 260-430 stems per acre. Ten percent had been fertilized once with 400 pounds urea per acre from 1970-1976. Fifteen percent had been both thinned and fertilized to the above specifications. The remaining plantations received no silvicultural treatments.

In September 1977, all recently killed and dying trees in each plantation were counted from a Hughes 500 helicopter. A total of 1,800 acres was surveyed in about 4 hours at a cost of $739. Recently killed and dying trees were easily counted since their color contrasted sharply with green healthy trees from the air (Figure 3). Dead trees without needles were difficult to detect from the air, and their numbers were estimated based on ground surveys.

Eleven plantations were randomly selected from the 43 for ground checking. Selections were weighted to give proportionate numbers based on silvicultural treatment and method of tree establishment. In August 1977, at least one fixed-area (1/10-acre) circular plot was established in areas of highest mortality in each plantation to examine as many dead and dying trees as possible and determine cause of death. At least one plot was established in an area with no mortality in each of the same plantations.

Within each plot, species and diameter at ground line were recorded for all stumps. Stumps and major lateral roots were partially excavated and dissected to reveal fungal sporophores or decay. Samples of decayed wood were returned to the laboratory and cultured on agar medium to identify all pathogenic root and butt decay-causing fungi. Nonpathogenic fungi causing decay were also identified if decay caused by pathogenic fungi was absent.

Mineral soil was collected to a depth of 9 inches with a soil auger at four random locations within each plot and pooled to one sample. Samples were analyzed in Portland for moisture content, and by the Soils Testing Laboratory, Oregon State University, for pH, organic matter, total nitrogen, potassium, and phosphorus content.

The following data were collected for each plot tree: (1) Species, (2) dbh, (3) crown condition (green full, green sparse, chlorotic, red, or no needles), and (4) cause of mortality. Root diseases were diagnosed by excavating root collars and major roots on each tree, and removing small sections of bark. Entire root systems were excavated on 24 trees in one plantation. All data were analyzed by stepwise regression.

Results

Total calculated mortality for 39 plantations averaged 1.1 trees per acre (Table 1 and 2). Four of the 43 plantations were not included in statistical analysis because three had missing data and one had severe bear damage. Proportion of old mortality to recent mortality was calculated to be 3:2 based on examination of the 11 ground checked mortality plots. Old mortality was calculated by multiplying recent mortality figures (counted from the helicopter) by 1.5. Total calculated mortality was the sum of old mortality and recent mortality.

All dead trees and nearly all chlorotic trees examined in the 11 mortality ground plots had root collar infections (Table 3). Eleven percent of all green "healthy" trees in infected plots also had root collar infections. More green trees were probably infected, but infection was not detected since, in most cases, entire root systems were not examined.

Two-thirds of all mortality was caused by *Armillaria mellea*, which was identified by the presence of white mycelial fans beneath the root collar bark (Figure 4). One-third of all mortality was caused by *Phellinus weirii*, which was identified by the presence of ectotrophic mycelium on the bark of infected roots (Figure 5). Two plots had mortality caused by both root pathogens, but they were not found together on the same trees. Although no other root diseases were detected on plot trees, *Verticicladiella wagenerii*, causal agent of black stain root disease (Figure 6), was observed in declining trees along roadways in the vicinity of examined plantations. One plantation (number 18) experienced severe damage caused by black bears (*Euractos americanus*) resulting in extensive tree mortality. Of four conifer species observed in mortality plots, Douglas-fir had the highest incidence of infection by root pathogens (38 percent). Douglas-fir and Pacific silver fir (*Abies amabilis*), suffered the highest mortality (25 percent, Table 3). *Armillaria mellea* killed 18 percent of the Douglas-fir in mortality plots. Western hemlock and western redcedar were also killed by *A. mellea* (4 percent and 6 percent, respectively).

Douglas-fir and western hemlock were killed by *P. weirii* (7 percent and 2 percent, respectively), but neither western redcedar nor Pacific silver fir were killed. Western redcedar is considered resistant to *P. weirii*, while Pacific silver fir is highly susceptible (only eight Pacific silver fir were examined) (Childs 1970, Hadfield and Johnson 1977). Only Douglas-fir was planted; the other species regenerated naturally.

Although treatment means showed differences, no statistically significant ($P = 0.05$) relationships occurred between total mortality and plantation age, elevation, stocking density, method of tree establishment, or silvicultural treatment (Table 2). Small sample size and considerable variation in incidence of mortality among plantations receiving the same treatment may account for the lack of statistically significant correlations.

A total of 214 stumps, most greater than 20 inches diameter at ground level, were superficially examined in 19 ground plots. Thirty-three percent of all western hemlock stumps, the primary species, had advanced decay caused by *Fomitopsis annosa (Fomes annosus)* (Table 4). Fifteen percent of all Douglas-fir stumps had advanced decay caused by *P. weirii*. No decay was detected in western redcedar stumps. *A. mellea* was detected in only 7 percent of all stumps examined.

Stepwise regression between incidence of tree mortality due to root disease and various plot parameters resulted in the following significant ($P = 0.01$) positive correlations (Table 5):

1. Percent tree mortality due to *P. weirii* and number per acre of old-growth stumps decayed by *P. weirii*--$r^2 = 0.82$.

2. Percent tree mortality due to *A. mellea* and number per acre of old-growth stumps decayed by *F. annosa*--$r^2 = 0.48$.

3. Percent total tree mortality and number per acre of old-growth stumps decayed by *F. annosa*--$r^2 = 0.67$.

There were no significant relationships between soil reaction, moisture, organic matter, or nutrients and tree mortality due to root diseases (Table 6).

Discussion

Total calculated mortality for 42 plantations averaged 1.1 trees per acre, mostly caused by *Armillaria mellea* or *Phellinus weirii*. Such a small figure would represent an insignificant loss if mortality was distributed evenly throughout plantations. However, mortality due to root diseases most often is distributed unevenly and usually occurs as clumps or patches of trees that ultimately may coalesce to form disease centers. In several infected plantations, mortality of 20 to 30 trees was confined to one section of a plantation. Such losses resulted in understocked openings 1/10 to 1/4 acre in size. No determination was made of total area understocked due to root diseases.

Total mortality was not correlated significantly with plantation age, elevation, stocking density, silvicultural treatment, or method of establishment. Planting Douglas-fir on poor sites or with poor technique

can result in increased infection (Buckland 1953). Previous studies in Newfoundland have shown that root disease caused by *A. mellea* is more severe when bare root stock is planted than when containerized seedlings or direct seeding are used (Singh 1975). There are no Pacific Northwest data available to compare methods of regeneration regarding mortality by root diseases.

Effects of thinning on infected plantations are little known. In one evaluation concerning precommercial thinning of ponderosa pine (*Pinus ponderosa*) in central Oregon, crop tree mortality caused by *A. mellea* was less in thinned stands (Johnson 1974). Similar work will begin this summer by Forest Insect and Disease Management pathologists to compare effects of precommercial thinning in infected and uninfected plantations of Douglas-fir in Oregon.

Research also has been rather limited on effects of fertilizer applications in plantations infected with root diseases. On Vancouver Island, Canada, urea and nitrate fertilizers failed to inhibit root disease caused by *Phellinus weirii* in a 26-year-old Douglas-fir plantation (Wallis and Reynolds 1974). Effects of fertilizers on *A. mellea*-infected plantations of Douglas-fir are unknown.

Observations in British Columbia on sites similar to those on the Quilcene Ranger District suggest that when *A. mellea*-infected Douglas-fir stands reach 20 to 30 years old, mortality will become insignificant (Johnson et al. 1972). Most plantations observed in the Quilcene evaluation were less than 20 years old. However, as a general rule, *A. mellea*-caused mortality is not as common in Douglas-fir stands over 30 years old as it is in younger stands in western Washington and Oregon. Johnson et al. (1972) also observed that 80 percent of trees with foliage discoloration only will recover fully, but less than 25 percent of trees with root collar infections will survive. In a severely infected plantation, our observations of 24 totally excavated Douglas-fir in all states of decline showed that 89 percent of all chlorotic trees and 66 percent of green "healthy" trees already had *A. mellea* root collar infections. Observations of infected plantations on the Quilcene District will be continued in order to monitor mortality as plantations mature.

Tree mortality due to root pathogens has been associated commonly with presence of adjacent large infected stumps (Rishbeth 1951, Wallis and Reynolds 1970, and Singh 1975). Root fungi spread from stump to tree when healthy roots contact infected stump wood.

Advanced decay caused by either *Fomitopsis annosa* or *Phellinus weirii* can be detected visually in old-growth timber after harvesting. Western hemlock infected with *F. annosa* is butt-rotted often to the point of being hollow. Old-growth trees infected with *P. weirii* have either a characteristic crescent-shaped stain on the cut stump surface or a laminated decay. Infections of *Armillaria mellea* in old-growth trees cannot be detected visually since infections often occur on buried lateral roots with no stain or decay evident in the stump.

Superficial examination of old-growth stumps showed that only 7 percent were infected with *A. mellea*, hardly enough to account for the unusually large proportion of Douglas-fir being infected and killed by *A. mellea*. Several stumps, especially those infected with *F. annosa* may also have *A. mellea* infections well below ground line or on distal portions of

lateral roots that were not examined. Further excavation of old-growth stumps is needed to determine if *A. mellea* occurs on such roots.

Favorable environmental conditions for the pathogen, possible nutrient imbalances, and large quantities of infected root material all may have contributed to the unusually severe mortality in some plantations observed in this investigation. Further observations are necessary to determine possible interactions between *A. mellea* and *F. annosa*, and their relation to Douglas-fir mortality. More research is needed concerning interactions of root disease fungi since complexes of several pathogens may play a greater role in forest disease problems than has been realized previously.

Summary

1. Forty-three plantations of 9- to 27-year-old Douglas-fir were aerially surveyed with ground checks to determine incidence and cause of tree mortality.

2. Total calculated mortality averaged only 1.1 trees per acre, but was clustered within plantations, resulting in understocked openings 1/10 to 1/4 acre in size.

3. Most mortality was caused by root pathogens. Two-thirds due to *Armillaria mellea* and one-third due to *Phellinus weirii*.

4. Of four conifer species observed, Douglas-fir had the most infection by root pathogens. Western redcedar had the least.

5. Small sample size and large variability within treatments may have prevented statistically significant correlations between total mortality and plantation age, elevation, planting density, method of establishment, or silvicultural treatment.

6. Thirty percent of all residual stumps of western hemlock had advanced decay caused by *Fomitopsis annosa*, 15 percent of Douglas-fir stumps had advanced decay caused by *P. weirii*, and 7 percent of all stumps were infected by *A. mellea*.

7. There was a significant ($P = 0.01$) increase in tree mortality due to root diseases with an increase in the number of stumps decayed by root pathogens.

8. Old-growth stumps decayed by *F. annosa* may have infections by *A. mellea* which were not detected and which may have contributed to Douglas-fir mortality.

9. Additional work is needed to determine effects of silvicultural treatments and root pathogens complexes on tree infection and mortality, especially in Douglas-fir plantations.

Recommendations

Root disease pathogens are present in almost every forest plantation, especially where numerous residual stumps are present. Root pathogens never can be eradicated totally from a site, but damage can be minimized by the following steps:

1. When establishing plantations that contain stumps decayed by root pathogens, plant or regenerate naturally with less susceptible native species, such as western hemlock or western redcedar.

2. Plantations with light scattered mortality due to root diseases and with moderate to heavy stocking can be thinned lightly to leave a slight overstocking. Favor hemlock or cedar when thinning in diseased areas.

3. If mortality due to root diseases is heavy, do not thin severely infected areas since most surrounding green trees are already infected and will probably die.

4. Present silvicultural treatments such as thinning and fertilizing do not appear to be aggravating infection and mortality by root diseases and, therefore, could be continued.

5. If root diseases are detected when stands are being harvested, FIDM can assist in determining the disease potential of such sites and suggest recommendations to alter planting methods if risk is high.

Prepared by:

Gregory M. Filip

GREGORY M. FILIP, Pathologist
Forest Insect and Disease Management
State and Private Forestry

Prepared by:

Donald J. Goheen

DONALD J. GOHEEN, Pathologist
Forest Insect and Disease Management
State and Private Forestry

Reviewed by:

James S. Hadfield

JAMES S. HADFIELD, Pathologist
Forest Insect and Disease Management
State and Private Forestry

Reviewed by:

Paul E. Buffam

PAUL E. BUFFAM, Director
Forest Insect and Disease Management
State and Private Forestry

Approved by:

Frank J. Kopecky

FRANK J. KOPECKY
Deputy Regional Forester
State and Private Forestry

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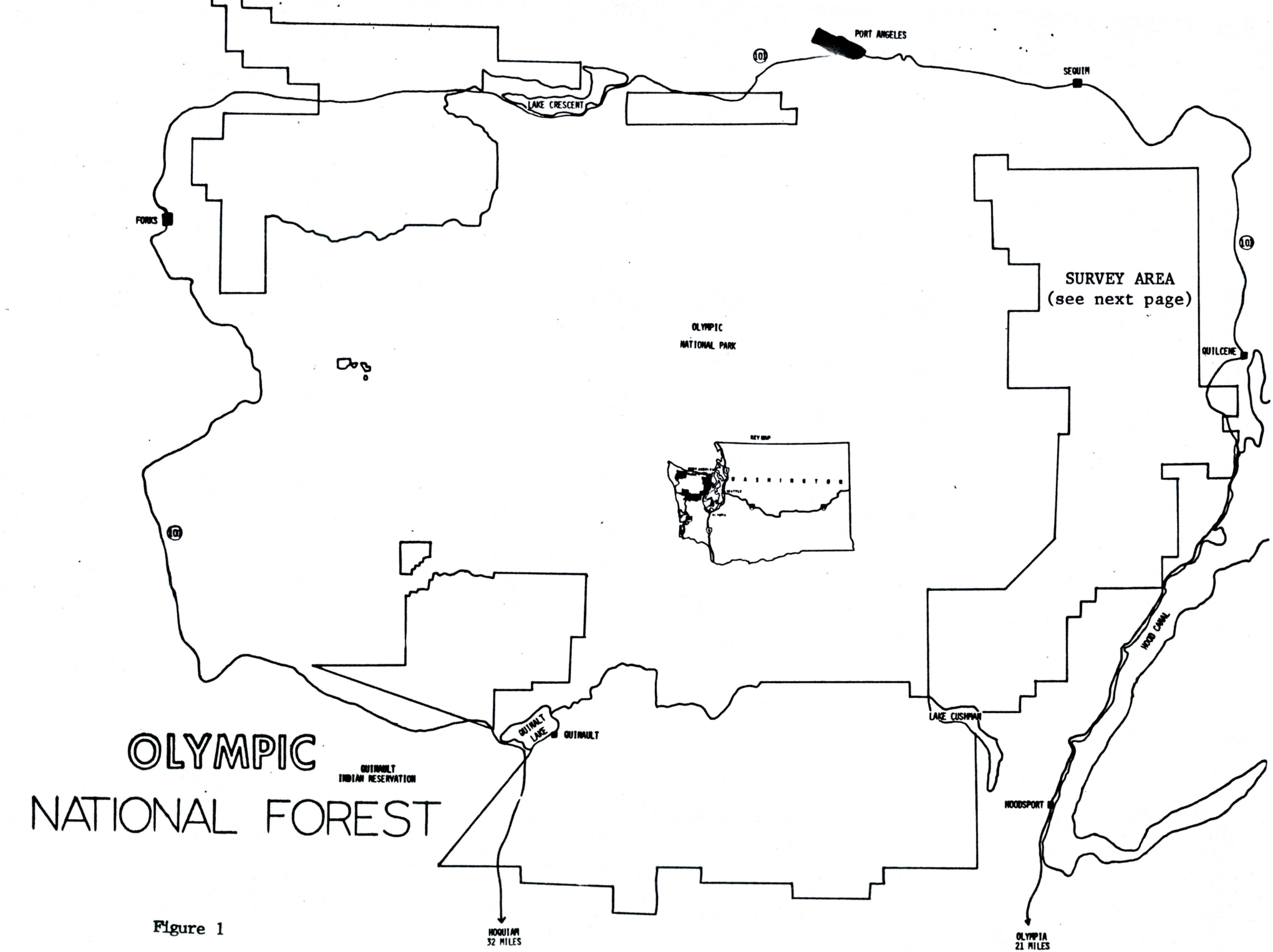
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Figure 1

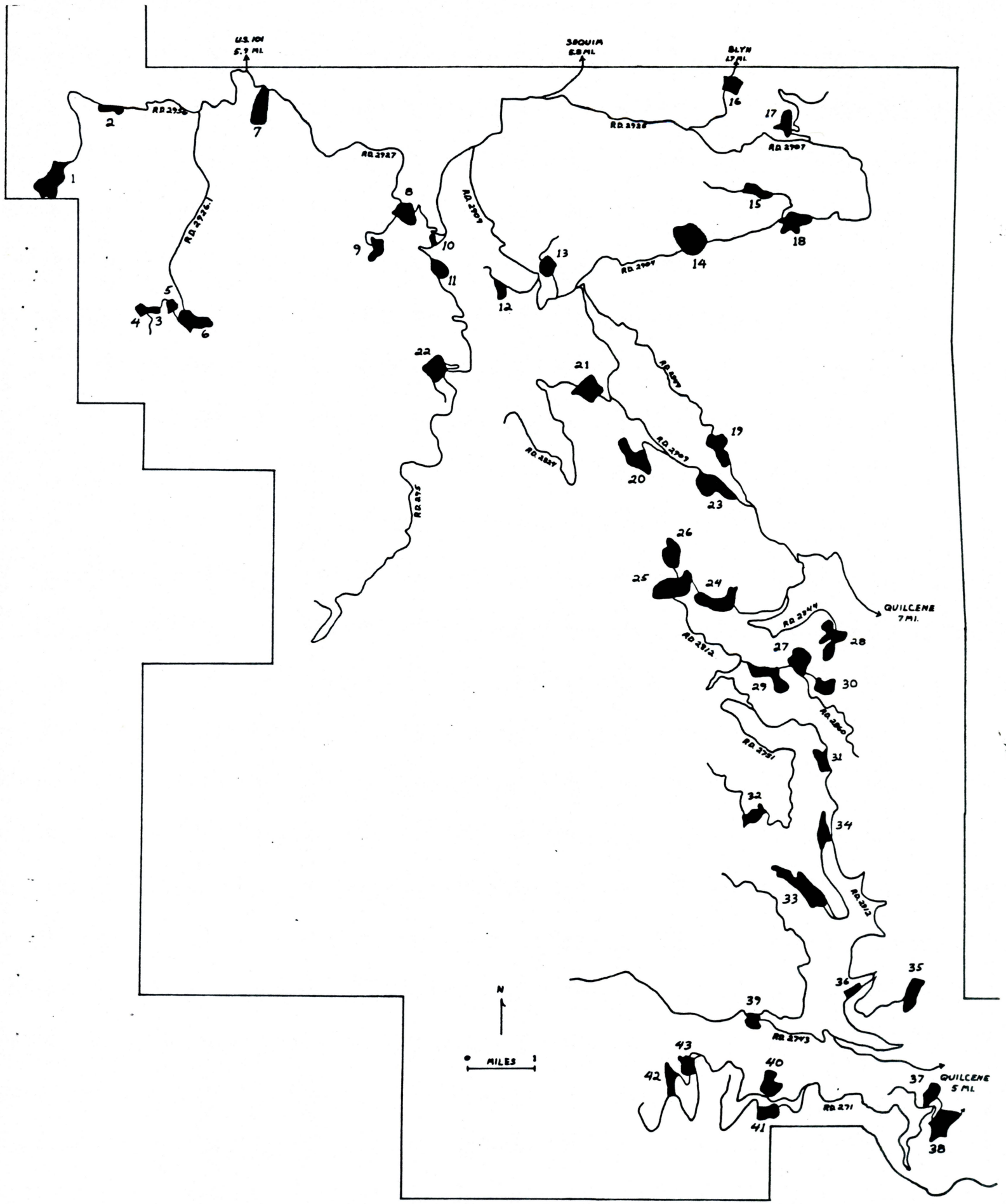

Figure 2. Map of Quilcene Ranger District showing location of plantations surveyed from the air (see Table 1).

Figure 3--Douglas-fir mortality caused by root diseases as seen from helicopter at high and middle altitudes. Age of trees is about 15 years.

Figure 3 --Douglas-fir mortality caused by root disease as seen from helicopter at low altitude.

Figure 4 --White mycelial fans of *Armillaria mellea* beneath bark of an infected Douglas-fir.

Figure 5--White ectotrophic mycelium of *Phellinus weirii* on root surface of an infected Douglas-fir.

Figure 6--Black stain in sapwood caused by *Verticicladiella wagenerii* in an infected Douglas-fir.

Table 1--Description of 43 Douglas-fir plantations aerially surveyed on the Quilcene Ranger District, Olympic National Forest, Washington.

Map Number	Total Mortality (Trees/Acre)	Number of Ground Plots	Method of[b] Establishment	Silvicultural[c] Treatment	Stocking Density (Trees/Acre)	Age (Years)	Midpoint Elevation (Feet)
1	0.03		2	1	?	13	3,000
2	0		2	4	260	13	1,500
3	0		3	1	278	10	3,000
4	0.21		1	1	678	10	3,300
5	0.36	2	1	1	250	10	3,000
6	0.89		1	1	510	13	2,750
7	0.95		1	1	1,000	10	1,500
8	0.11	2	1	1	253	10	1,300
9	0.13		1	1	1,313	12	1,250
10	0.25	1	1	4	260	18	1,250
11	0.83		3	4	260	18	1,500
12	5.63		1	4	436	18	2,150
13	1.61		1	2	260	17	2,350
14	1.87	2	1	3	2,000	15	2,200
15	0		2	1	3,295	9	1,750
16	1.07		1	1	1,500	12	900
17	0.48		2	1	2,581	9	900
18	2.33[a]	2	1	4	260	18	1,500
19	1.66		1	3	380	13	2,750
20	1.04		1	1	355	13	2,650
21	0.51	3	1	1	?	12	2,250
22	5.59		1	1	320	14	3,000
23	0.09		1	3	410	15	3,000
24	1.03		2	1	300	23	2,400
25	1.00	2	1	1	470	23	3,200
26	1.50	2	1	1	500	19	3,750
27	0.38	1	3	1	?	18	3,550
28	0.36	2	2	1	1,000	17	2,000
29	0.87		3	1	766	14	4,000
30	0.24		1	1	666	15	3,500
31	1.29		1	4	436	20	2,400
32	1.55		1	1	1,500	11	3,250
33	0.39		1	2	1,000	12	2,000
34	2.00		1	4	436	20	2,000

Table 1--Description of 43 Douglas-fir plantations aerially surveyed on the Quilcene Ranger District, Olympic National Forest, Washington (cont.)

Map Number	Total Mortality (Trees/Acre)	Number of Ground Plots	Method of[b] Establishment	Silvicultural[c] Treatment	Stocking Density (Trees/Acre)	Age (Years)	Midpoint Elevation (Feet)
35	1.93		1	1	300	17	2,500
36	0.77		1	2	300	22	2,000
37	0.31		1	2	360	26	1,650
38	0.71		1	3	580	27	1,500
39	1.84		1	1	350	9	1,750
40	1.08		1	1	350	10	2,750
41	0.56		1	1	500	17	3,500
42	0		1	1	2,350	10	3,250
43	2.23		1	1	1,100	14	3,250
Average	1.08		-	-	753	15	2,394

[a]Mortality is primarily bear damage. Only recent mortality is listed.

[b]Method of establishment: 1 = planted, 2 = seeded, 3 = natural regeneration. Many planted plantations also had natural regeneration.

[c]Silvicultural treatment: 1 = none, 2 = thinned, 3 = fertilized, 4 = both thinned and fertilized.

Table 2--Treatment means for 39[a] plantations with Douglas-fir mortality caused by *Armillaria mellea* and *Phellinus weirii*

	Method of Establishment				Silvicultural Treatment[b]				
	Planted	Seeded	Natural	Total	None	Thinned	Fertilized	Both	Total
Number of Plantations	31	5	3	39	25	4	4	6	39
Total Mortality (Trees/Acre)	1.2	0.4	0.6	1.1	1.0	0.8	0.9	1.7	1.1

	Stocking Density (Trees/Acre)				Age (Years)				Elevation (Feet)			
	200-600	601-1,000	> 1,000	Total	10-15	16-20	> 20	Total	0-1,500	1501-3,000	> 3,000	Total
Number of Plantations	25	6	8	39	24	10	5	39	9	21	9	39
Total Mortality (Trees/Acre)	1.3	0.5	0.9	1.1	0.9	1.6	0.8	1.1	0.5	1.4	0.9	1.1

[a]Four of 43 plantations were not included in statistical analysis

[b]Plantations were thinned to 260-430 stems/acre. Fertilizing was with one application of 400 lbs. urea/acre

Table 3--Infection and mortality caused by *Armillaria mellea* and *Phellinus weirii* in four conifer species on eleven mortality plots.

Species	Total Number	Ave. DBH (In.)	Healthy (%)	Infected (%)								
				Phellinus weirii			*Armillaria mellea*			Total		
				Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
Douglas-fir	143	3.9	62	7	7	14	6	18	24	13	25	38
Western hemlock	54	4.2	87	0	2	2	7	4	11	7	6	13
Western redcedar	17	7.6	88	0	0	0	6	6	12	6	6	12
Pacific Silver fir	8	8.2	75	0	0	0	0	25	25	0	25	25
Total	222	4.4	70	5	5	10	6	14	20	11	19	30

Table 4--Percent of old-growth stumps decayed by pathogenic fungi in eleven young-growth Douglas-fir plantations.

Species	Total Number Examined	No Decay	Decayed and Pathogen Present			
			Phellinus weirii	*Armillaria mellea*	*Fomitopsis annosa*	Non-pathogenic[a] Fungi
		Percent				
Western hemlock	144	38	7	9	33	14
Douglas-fir	48	77	15	6	8	0
Western redcedar	22	100	0	0	0	0
Total	214	53	8	7	24	9

[a]Primary non-pathogenic fungi causing decay included *Ganoderma applanatum* and *Fomitopsis pinicola*

Table 5--Stocking density and pathogenic decay fungi inhabiting old-growth western hemlock and Douglas-fir stumps in plots with Douglas-fir mortality.

Cause of Plantation Mortality	Number of Plots	Total Number	No Decay	*Phellinus weirii*	*Armillaria mellea*	*Fomitopsis annosa*	Non-Pathogenic Fungi[b]
		stumps per acre					
Phellinus weirii (PW)	4	~~103~~ 118	~~30~~ 46	28[c]	5	25	~~15~~ 3
Armillaria mellea (AM)	5	~~100~~ 122	~~37~~ 42	4	10	34[c]	~~15~~ 12
PW or AM	7[a]	~~111~~ 114	~~43~~ 46	17	9	32[c]	10
None	12	~~103~~ 104	~~56~~ 70	3	6	8	17
Total	19	106	61	8	7	16	14

aTwo plots had mortality caused by both *P. weirii* and *A. mellea*.

bPrimary non-pathogenic fungi causing decay included *Ganoderma applanatum* and *Fomitopsis pinicola*.

cSignificant (P = 0.01) correlation with cause of mortality.

Table 6--Soil reaction, moisture, organic matter, and nutrient levels in plots with Douglas-fir mortality

Cause of Mortality	Number of Plots	pH	Moisture	Organic Matter	Total Nitrogen	Potassium	Phosphorus
			percent			ppm	
Phellinus weirii (PW)	4	5.4	22.2	4.7	0.14	176	55
Armillaria mellea (AM)	5	5.5	27.3	9.0	0.12	289	20
PW or AM	7	5.4	24.9	7.5	0.13	254	39
None	12	5.6	21.2	7.7	0.13	202	30
Total	19	5.5	22.6	7.6	0.13	221	33